7th Int. Symp. "Nanostructures: Physics and Technology" **EN.03**
St Petersburg, Russia, June 14–18, 1999


# Magnetooptics of the excitonic states in the shallow GaAs/AlGaAs quantum wells

N. N. Sibeldin†, *M. L. Skorikov*†, V. A. Tsvetkov† and B. Etienne‡

† Solid State Physics Division, P. N. Lebedev Physical Institute, Moscow, Russia
‡ Laboratoire de Microstructures et de Microelectronique, CNRS, Banno, France

**Abstract.** Photoluminescence (PL) and photoluminescence excitation (PLE) spectra of asymmetric two-well GaAs/$Al_{0.05}Ga_{0.95}As$ structures with tunnel-isolated shallow quantum wells (QW) in magnetic field oriented both perpendicular and parallel to the layers were studied at liquid helium temperatures. In the PLE spectra we observed the lines, which most probably correspond to absorption by excitons, formed by a QW localized carrier and a free carrier of opposite sign, attracted by the Coulomb force. Clear indication of effective excitation transfer between the wide and narrow wells of the structure was observed, which is apparently due to the resonant excitation of the light-hole excitons in the wide well by recombination radiation from heavy-hole excitons in the narrow well.

The nature of electronic states in the structures with shallow quantum wells (QW) that have a single confined state for each type of quasiparticles, is an interesting subject to study. For instance, in type-I structures with shallow wells, additional bound states of excitonic type, formed due to the Coulomb attraction between the charge carriers, one of which resides in the quantum-confined state, and the other one in the continuum, should gain importance due to the limited number of singleparticle discrete levels in such a system. Similar states (the "Coulomb-well excitons") were observed in the structures close to type I – type II transition (i.e., those with nearly zero band offset for one type of the carriers) [1, 2]. It is also convenient that for low-barrier structures the tuning range of the Ti-sapphire laser is quite enough to study both confined and unconfined states by the photoluminescence excitation (PLE) spectroscopy technique.

In this work, we studied the spectra of photoluminescence (PL) and PLE of GaAs/$Al_{0.05}Ga_{0.95}As$ double-well structures, grown by MBE technique at the Laboratoire de Microstructures et de Microelectronique, (Banno, France). Wide and narrow QWs of width $w_1 = 40$ Å, and $w_2 = 30$ Å were separated by the tunnel-untransparent barrier of width $b = 600$ Å. For aluminium concentration in the barrier layer $x = 0.05$, the depth of the potential well for electrons is nearly 45 meV, that for holes is about 30 meV. The PL was excited and PLE spectra were taken with the use of a Ti-sapphire laser. Magnetic field up to 5.5 T was created by a superconducting solenoid. The sample temperature was held at 2 K.

The zero-field PL and PLE spectra are shown in Fig. 1. In the PL spectrum, two narrow lines $HH_1$ and $HH_2$ are present; obviously, they correspond to the recombination of heavy-hole excitons in the wide and narrow well, respectively. The PLE spectra were taken by setting the spectrometer approximately at the half-maximum position on the low-energy side of either $HH_1$ or $HH_2$ peak. In the absence of any coupling between the wells, one should obtain in these two cases the spectra, typical for the single QWs of corresponding width. Both experimentally observed spectra contain the expected lines, corresponding to excitation of heavy- and light-hole excitons in the wide and narrow QWs ($HH_1$, $LH_1$, and

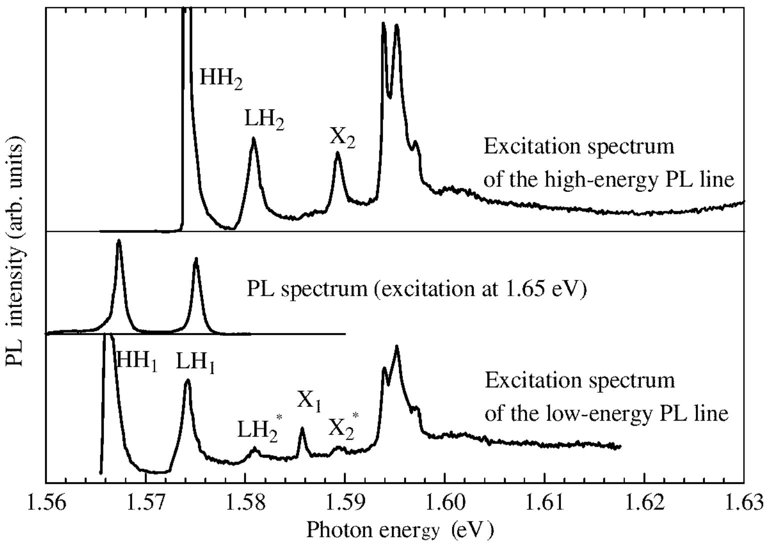


**Fig. 1.** PL and PLE spectra at zeromagnetic field

HH$_2$, LH$_2$, respectively). Besides, one can clearly see additional lines X$_1$, X$_2^*$, and LH$_2^*$ in the wide-well, and X$_2$ in the narrow-well spectra; both spectra contain an intense triplet at 1.593–1.598 eV, as well. Comparing the two PLE spectra in Fig. 1, one can conclude that the energy of the heavy-hole exciton transition HH$_2$ in the narrow QW nearly coincides with that of the light-hole exciton transition LH$_1$ in the wide QW ($h\nu \simeq 1.574$ eV). Also, transitions into the excited states of the heavy-hole excitons in each well fall within the corresponding light-hole exciton line; this can be seen from the PLE spectra taken under magnetic field applied perpendicular to the layers (Fig. 2). Magnetic-field dependencies of the energies of the transitions into the $2s$, $3s$, and $4s$ heavy-hole exciton states in each well are outlined there by thin solid lines. Extrapolation to zero field gives the energies of these transitions in the absence of magnetic field, which enabled us to evaluate the binding energies of the heavy-hole excitons in the narrow and wide QWs as 6.4 and 7.2 meV, respectively.

Let us now consider the nature of the additional lines in the PLE spectra (leaving out the discussion of the above-mentioned triplet structure, because this requires extra studies). First, it can be seen from the comparison of the zero-field spectra in Fig. 1 that the line X$_1$ at $h\nu \simeq 1.586$ eV in the PLE spectrum of the wide QW is related to the state localized in that well, because it is absent in the narrow-QW spectrum. As no transitions between the confined states of electrons and holes, apart from those discussed above, can be expected in our shallow QWs, we believe that this line correspond to the transition between the confined state of one type of particles (most probably, electron) and the unconfined state of the oppositely charged particle. More exactly, an excitonic state should be formed, in which, say, electron resides in the confined state within the QW, and the hole (with single-particle energy above the barrier) is localized near this well by the Coulomb attraction to the electron. Thus, the electron, constituting such an exciton will be quasi-twodimensional, while the hole state will be closer to a three-dimensional one. The fact that the diamagnetic shifts of the HH$_1$ and X$_1$ lines in perpendicular field are of the same order of magnitude

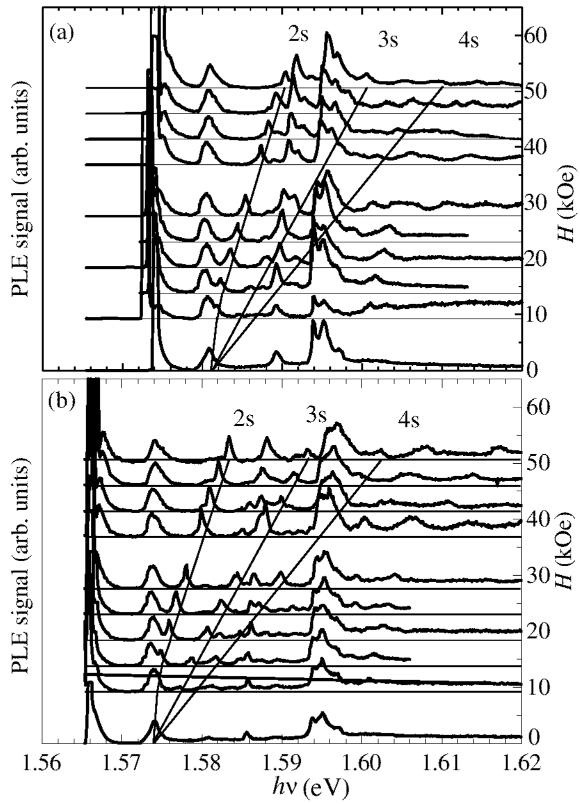


**Fig. 2.** Excitation spectra of the narrow-well (a) and the wide-well (b) in perpendicular magnetic field. All spectra are normalized to the respective LH peaks. The vertical shift of the curves is proportional to the field strength at which they were taken (right-hand scale).

(about 1.4 and 2.4 meV in the perpendicular field of $H = 5$ T, respectively) seems to corroborate indirectly our interpretation of the nature of the latter. Apparently, the $X_2$ line in the narrow-well PLE spectrum, whose intensity is comparable to that of the light-hole exciton line, is of the same nature. The diamagnetic shifts of the peaks $HH_2$ and $X_2$ in perpendicular field of $H = 5$ T are 1.4 and 2.6 meV, respectively.

Two lines, $LH_2^*$ and $X_2^*$, in the PLE spectrum of the wide QW coincide very well in their spectral position with the two lines in the narrow QW spectrum, $LH_2$ and $X_2$, respectively, although the intensities of the former are significantly lower (Fig. 1). Appearance of the coinciding peaks in the PLE spectra of the two QWs indicates the existing of some sort of coupling between the wells. Tunneling coupling is unfeasible because of the large thickness of the separating barrier ($b = 600$ Å). Non-relevance of the tunneling coupling is further confirmed by the weak influence of the inplane magnetic field, which should reduce the rate of tunneling between the QWs [3, 4], on the intensities of $LH_2^*$ and $X_2^*$ peaks (Fig. 3). Meanwhile, application of the field perpendicular to the layers result in obvious quenching of these peaks (see Fig. 2(b)). We suppose that the most probable explanation of this quite efficient coupling between the wells is the occurence of the resonant excitation of the light-hole excitons in the wide QW (with their further relaxation into heavy-hole excitonic

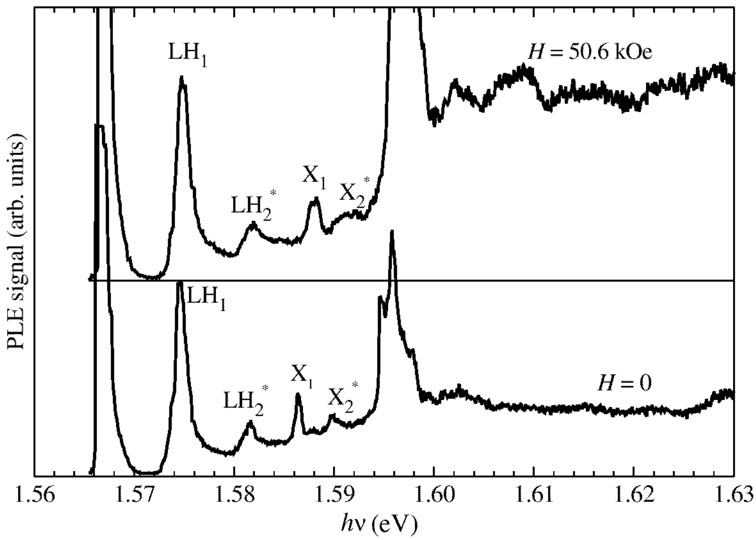


**Fig. 3.** Influence of the parallel magnetic field on excitation spectrum of the wide-well PL

states) by the recombination radiation emitted by the heavy-hole excitons in the narrow well. As it has been pointed out above, the energies of these two transitions are virtually the same. Under application of perpendicular magnetic field, the difference in diamagnetic shifts results in the detuning of resonance (cf. Figs. 2(a) and 2(b)); in the parallel field, the diamagnetic shifts of both lines are small, and the resonance is conserved.

This work was partially funded by the Russuan Foundation for Basic Research (project No 96-02-18237), Russian Ministry of Science and Technology through the Programs "Physics of Solid-State Nanostructures" (No 97-1050) and "Fundamental Spectroscopy" (No 2.6), and the State Program of Support for the Leading Scientific Schools (No 96-15-96341).

## References

[1] J. Warnock, B. T. Jonker, A. Petrou et al., *Phys. Rev. B* **48**, 17321 (1993).
[2] A. V. Kavokin, M. A. Kaliteevski, S. V. Goupalov et al., *Phys. Rev. B* **54**, 11078 (1996).
[3] A. I. Filin, K. v. Klitzing, I. V. Kukushkin et al., *Pis'ma v Zh. Eksp. Teor. Fiz.* **61**, 684 (1995).
[4] M. L. Skorikov, I. I. Zasavitskii, I. P. Kazakov et al., *Pis'ma v Zh. Eksp. Teor. Fiz.* **62**, 500 (1995).